Conditions on Early Mars Might Have Fostered Rapid and Early Development of Life

Everett K. Gibson[1], David S. McKay[1], Kathie L. Thomas-Keprta[2], Simon J. Clemett[2] and Susan J. Wentworth[2]
[1]KR Astromaterials Research Office, NASA Johnson Space Center, Houston, TX 77058 and [2]ESCG, NASA Johnson Space Center, Houston, TX 77058

The exploration of Mars during the past decades has begun to unveil the history of the planet. The combinations of remote sensing, *in situ* geochemical compositional measurements and photographic observations from both above and on the surface have shown Mars to have a dynamic and active geologic evolution. Mars' geologic evolution clearly had conditions that were suitable for supporting life. For a planet to be able to be habitable, it must have water, carbon sources, energy sources and a dynamic geologic past. Mars meets all of these requirements.

The first 600 My of Martian history were ripe for life to develop because of the abundance of (i) Water-carved canyons and oceans or lakes with the early presence of near surface water shown by precipitated carbonates in ALH84001 well-dated at ~3.9 Gy. , (ii) Energy from the original accretional processes, a molten core which generated a strong magnetic field leaving a permanent record in the early crust, early active volcanism continuing throughout Martian history, and, and continuing impact processes, (iii) Carbon and water from possibly extensive volcanic outgassing (i.e. H_20, CO_2, CH_4, CO, O_2, N_2, H_2S, SO_2, etc.) and (iv) some crustal tectonics as revealed by faulting and possible plate movement reflected by the magnetic pattern in the crust. The question arises: "Why would life not evolve from these favorable conditions on early Mars in its first 600 My?" During this period, it seems likely that environmental near-surface conditions on Mars were more favorable to life than at any later time. Standing bodies of water, precipitation and flowing surface water, and possibly abundant hydrothermal energy would all favor the formation of early life. Even if life developed elsewhere (on Earth, Venus, or on other solar systems) and was transported to Mars, the surface conditions were likely very hospitable for that introduced life to multiply and evolve.

We make two basic assumptions for this hypothesis:

(1) Living systems appeared on the surface of Mars as a result of the interaction of primary energy source with some set of primordial molecules present on the surface of Mars, and that scenario could occur early and rapidly.

(2) When conditions were favorable, life could start rather quickly; the commonly stated requirement that life would need hundreds of millions of year to get started is only an assumption; perhaps it could start in a very short interval during the first tens of millions of years after crustal formation. Even with impact-driven extinction events, such a short start-up time would allow life to restart multiple times until it persevered. If panspermia is considered, life could be introduced as soon as liquid surface water was present and could instantly thrive and spread.

Magnetic fields were present on early Mars and they began to dissipate after 500 to 600 My (Connerrey et al., 1999; 2005). The magnetic fields protected Mars' surface from UV irradiation and allowed organic components to survive. The primordial soup which existed on early Mars fostered and produced the required ingredients for the development of life. Synthesis of organic compounds by hydrothermal Fischer-Tropsch reactions may have been typical in the volcanically active upper crust. Random cometary impacts on the Martian surface would only have enhanced these ingredients. The extensive bombardment of the inner solar system and the Martian crust around 3.9 Gy supplied additional volatiles and energy sources for chemical evolution to proceed. Impacts put extreme stress on any living system present on Mars and only the most adaptable survived. A very early start would allow time for organisms to evolve and occupy subsurface habitable niches where they might have been protected from even a major bombardment event at 3.9Gy. Because of the warmth and abundance of water on Mars in the first 600 My (Noachian period), it is likely that this evolutionary development could have occurred rapidly. With the thinning of the Martian atmosphere and changes in temperature, decline of the magnetic field, and increasing amounts of cosmic rays and UV irradiation getting to the surface, causing mutations in organisms near the surface after 3.9 Gy and during the Hesperian period in Mars history, only the hardy subsurface organisms survived. As the surface conditions became more harsh, organisms would adapt to the subsurface water and carbon reservoirs and would likely become chemistry dependent for their energy; electron donor and

acceptor systems (i.e. Fe-rich minerals etc.) driven by chemical disequilibria associated with the geologic processes.

During the post 3 Gy period of the Amazonian period, Mars underwent lower impacts, the UV irradiation on the surface was sufficient to destroy organic molecules and organisms. The "Cold and Dry" Late Mars period extended back at least 3 Gy from the present. Energies required for organisms to survive and Mars to be a habitable body were from geologic processes associated with subsurface aquifers and thermal energies associated with late-stage Martian volcanism. Even today evidence of volcanic events such as young cinder cones have been observed in the polar regions. Energies associated with late-stage polar caps, volcanism, and abundance of carbon species such as the frozen CO_2 polar cap would offer opportunities for organisms to find niches for Martian habitats to survive to the present-provided they escaped the UV flux by staying beneath the surface. Periodic episodes of wetter, warmer climate caused by obliquity changes may have enabled organisms to emerge into surface water and soils, only to retreat or hibernate when the dry, cold conditions returned.

All of the samples we have available from Mars to study are subsurface samples. The SNC meteorites are samples from 0.05 to 0.5 km beneath the Martian surface. From the 41 Martian meteorites available, there are no sedimentary surface materials. Evidence of pre-terrestrial aqueous alteration products and indigenous reduced carbon species have been identified within the least terrestrially altered Martian meteorites. The oldest Martian sample of the early crust is ALH84001 (crystallization age of 4.5 Gy) and containing carbonate of 3.9 Gy age. These carbonates show the presence of reduced carbon components (Clemett et al., 1998). McKay et al., (1996) and Gibson et al. (2001) have suggested that the morphological features, along with reduced carbon components are remnants of earlier biogenic processes. Thomas-Keprta et al. (2002, 2007.) have strengthen the arguments about biogenic processes occurring within this sample by their detailed studies of the magnetites within the carbonates of ALH84001. Oxygen isotopic compositions of the carbonates within ALH84001 suggest the fluids from which the carbonates were formed were in the 80^{o}C range (Romanek et al., 1994). These temperatures were suitable to support a host of organisms. The latest work of Thomas-Keprta et al., (2007) clearly shows a population of magnetites within the carbonates define a robust biosignature and are not the products of thermal decomposition of iron-bearing carbonates. With this being the case, it strongly supports the idea that microorganism similar to magnetotactic bacteria were present on Mars at 3.9 Gy because their magnetite by-products appear to be present within 3.9 Gy old carbonates. On earth, magnetotactic bacteria are fairly far along in the tree-of-life. The presence of similar bacteria on Mars at 3.9 Gy implies that life had already been around for a while, possibly several hundred million years. With formation of the magnetites at the period of time when the planet was undergoing heavy impact bombardment, changing from a "Warm and Wet Early Mars" to the transitional period of the Hesperian between 3.8 Gy to 3 Gy, organisms were stressed and trying to survive. The removal of the early magnetic field on Mars after 3.9 Gy, added to the stress of the organisms near the surface because of the destructive power of the solar flare events, cosmic rays, and increased UV resulting from a thinning atmosphere. Habitats beneath the Martian surface within the aquifers offered the required niches to survive. As we know from terrestrial organisms, if an organism or life was ever present, it does everything it can do to survive. Slowing down its metabolic processes and going dormant was clearly a survival mode option.

In terrestrial systems, organisms that undergo stress often produce biofilms (poly-saccharides) (Westall et al., 2001). The organism produce biofilms around themselves to form an environmentally "safe" site for escaping threatening conditions which might destroy them. Within samples of the SNCs there are abundant examples of biofilms (Gibson et al., 2001). Polysaccrides are one of the key ingredients in life's development for systems on the earth. Proteins, nucleic acids, lipids, and polysacchrides are of the four major biopolymers required for life, as we know life on the Earth. It stands to reason that if life on Mars follows the same evolutionary paths, the presence of any of these four constituents might constitute a biosignature. In addition, we have indigenous reduced carbon components with isotopic compositions of -15 to -20‰, along with nitrogen-bearing reduced organic components (Septhon et al., 2002) in the Nakhla SNCs. The requirement for nitrogen-bearing componets associated with biological processes on Mars has been suggested by Capone et al. (2006). Nakhla is a shergottite meteorite from Mars and has a crystallization age of 1.3 Gy. Nakhla has preterrestrial alteration products such as iddingsite that have been dated at 600 to 700 My age (Swindle and Olson, 2004). Within the preterrestrial alteration products such as carbonates, sulfates, clays (Wentworth et al., 2005) along with numerous morphological features similar to fossilized bacteria (Gibson et al., 2001 and Wentworth et al., 2005) have been observed. The

formation age (i.e. 1.3 Gy) of Nakhla is in the middle of the Amazonian period, when Mars was cold and dry. However, the sample was from beneath the surface of Mars and showed evidence of groundwater fluids interacting with the silicate host minerals. Clearly the subsurface of Mars was a site where microbial activity could have found a hospitable niche. This Martian groundwater table has recently been seen to be active with the fluid release activity observed on crater walls (Malin et al., 2006) and observations from the MARSIS onboard Mars Express and the MRO observations. Despite the surface of Mars being "cold and dry" abundant subsurface water is present. This water assists any habitat survivability on Mars. The interpretations that there may be biosignatures of Martian microbial life (McKay et al., 1996; Gibson et al., 2001; Thomas-Keprta et al., 2007) would be consistent with the concept that such life evolved early on Mars and then found ecological niches below the surface where temperatures and UV exposure were more amenable.

How does this early Martian life development hypothesis compare to Earth? Earliest evidence of cellular fossils occurs around 3.5 to 3.7 Gy ago. Perhaps life also developed on Earth well before the terminal cataclysm or end of the major bombardment period, but the late bombardment was violent enough on Earth to either prevent or extinguish any life prior to about 3.9 Gy; if life developed on Earth during this period, it was extinguished by the violence of the cataclysm ending at about ~3.9 Gy. On Mars, the terminal heavy bombardment was perhaps not as violent because of the lower impact velocities and fewer impactors; a less harsh bombardment may have spared already evolved microbial life.

If life did not develop on Earth till after the end of the heavy bombardment, another ~2 Gy passed on the Earth before significant development of multicellular and megascopic life occurred prior to the Cambrian Era and the development of simple skeletal life-forms. The production of an oxygen atmosphere around 2.2 Gy ago may have been the impetus of a more rapid evolutionary forced development leading to the rapid explosion that occurred at the beginning of the Cambrian period. Spectacular advances in life on Earth occurred within the last 500 my (Post-Cambrian Era) of Earth's history.

Perhaps the first 500 My years of Mars could have had conditions which favored the rapid evolutionary development of life, and this life escaped extinction by the late heavy bombardment. In that case, Mars had a good 500 My start on the Earth and may have developed relatively complex organisms much earlier. Development of life on Mars may have slowed after 3.9 Gy because of the reduction of magnetic field protection, the thinning atmosphere, and the harsher surface conditions. With the ability of impacts to remove samples from planetary surfaces, perhaps some of this early-developed Martian biota was removed and traveled to Earth. The arrival of these organisms would have jumped-started life on Earth anytime after 3.9 Gy by seeding with already evolved microbes which were developed during the first 600 My of Martian history, a time period when life on Earth was simply not possible. Earth then became a much more hospitable place for life to develop and flourish, and pulled way ahead of Mars. On Mars, even with the early start, the harsh conditions kept life from evolving beyond a relatively simple stage, although it has certainly had enough time for complex development, and Martian life may be more complex than is commonly assumed.

In our view, life is probably present on Mars today beneath the surface, possibly associated with the aqueous water reservoirs, the ice-rich areas near the poles, and equatorial frozen lakes and outwash features. If our hypothesis for an early rapid development of life on Mars is correct (as supported by the inferred presence of magnetotactic bacteria at 3.9 Gy), Mars has perhaps had plenty of time to develop more complex and sophisticated microbes, limited only by the necessity of hiding in the subsurface and and the necessity to live off limited chemical energy and limited nutrients.

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